502

VOLUME 80 SEPARATE No. 502

PROCEEDINGS

AMERICAN SOCIETY OF CIVIL ENGINEERS

SEPTEMBER, 1954

PROBLEMS ENCOUNTERED IN IMPROVING A DEEP WATER HARBOR

by Harry Sugden, A.M. ASCE

WATERWAYS DIVISION

{Discussion open until January 1, 1955}

Headquarters of the Society
33 W. 39th St.
New York 18, N. Y.

PRICE $0.50 PER COPY

THIS PAPER

--represents an effort by the Society to deliver technical data direct from the author to the reader with the greatest possible speed. To this end, it has had none of the usual editing required in more formal publication procedures.

Readers are invited to submit discussion applying to current papers. For this paper the final date on which a discussion should reach the Manager of Technical Publications appears on the front cover.

Those who are planning papers or discussions for "Proceedings" will expedite Division and Committee action measurably by first studying "Publication Procedure for Technical Papers" (Proceedings – Separate No. 290). For free copies of this Separate—describing style, content, and format—address the Manager, Technical Publications, ASCE.

This paper was published at 1745 S. State Street, Ann Arbor, Mich., by the American Society of Civil Engineers. Editorial and General Offices are at 33 West Thirty-ninth Street, New York 18, N. Y.

PROBLEMS ENCOUNTERED IN IMPROVING DEEP WATER HARBOR

By Harry Sugden,[1] A. M. ASCE

SYNOPSIS

The problems encountered in the improvement or development of fresh water streams into deep water harbors are numerous and variable. The same problems are seldom encountered on any two projects. The laws governing the hydraulics of a fresh water stream are firmly established but very little is known or published on the laws governing the hydraulics of a tidal estuary. This discussion is limited solely to the Savannah Harbor and based on data obtained in connection with studies of the effect of past improvements and of problems now being encountered with possible corrective measures to be taken.

INTRODUCTION

Deep water harbors are the life blood of our country. Their development and improvement are a continuing problem as the draft of sea going vessels is constantly increasing. At the turn of the century a depth at low water of 20 feet was considered adequate for most harbors to meet the foreseeable needs. Today, a depth of 34 feet at low water is necessary to handle the majority of ships. Some of the larger freighters and liners require depths in excess of 34 feet and are therefore limited to the use of certain few harbors. This large increase in dimensions over those for which the harbor was originally designed is one of the major underlying causes of the numerous problems now being encountered. The maintenance of our deep water harbors is a constant problem and requires the expenditure of millions of dollars annually.

Prior to any attempt to study the many problems encountered in the improvement and maintenance of a deep water harbor, it is essential that a complete history of the harbor along with any improvements made and their effect on the regimen of the estuary be available. Where there is a fresh water stream of consequence entering the harbor a description of the drainage basin and a record of the discharges should also be reviewed. Due to the writer's familiarity with the Savannah Harbor and the lack of historical data on other harbors, it is intended to confine this paper strictly to this project.

1. Civil Engineer, Corps of Engineers, U. S. Army, Savannah District, Savannah, Ga.

History

The Savannah River rises in the Blue Ridge Mountains of North Carolina and flows southeasterly about 400 miles to its mouth. It drains an area of about 10,500 square miles which is divided into three distinct physiographic areas—Mountain, Piedmont and Coastal Plain. The areas are approximately 2,000, 5200 and 4400 square miles respectively. The maximum, average and minimum discharges at Clyo about 50 miles above Savannah are 280,000 cfs, 12,000 cfs, 2,800 cfs respectively. The river is one of the heavier silt bearing streams in the Southeast although its load is light compared to rivers of the midwest. There is a 9-foot navigation project authorized to Augusta, Georgia, a distance of about 200 miles. About 25 miles above Augusta, Georgia, there is a multiple purpose project, Clark Hill Dam, placed in operation in December 1951, with an installed capacity of 280,000 KW and about 2,500,000 acre feet of storage below full power pool. The minimum release from this project for navigation on the Savannah River is 5300 cfs. There are also 5 high head power developments in the head waters but due to the small drainage areas above they serve no use for regulation of river flows.

Prior to any improvement the lower portion of the Savannah River consisted of numerous channels and islands, through and around which the river flowed. This condition did not produce any one channel with depths adequate for ocean going ships. In its original condition there was a controlling depth of 13 feet at mean low water over the entrance bar and about 10 feet between the bar and the City of Savannah.

The first work of record performed in the Savannah Harbor to improve its regimen was the construction of Cross Tides Dam near the upper end of the harbor. This dam was constructed in about 1875 to prevent the diversion of water to Back River on the ebb tide. At the same time the river opposite the City of Savannah was widened to 575 feet and dredging was accomplished at various points between the city and the sea.

The first major improvements in the harbor were accomplished between 1882 and 1890 and consisted chiefly of raising Cross Tides Dam to mean high water to increase the ebb flow in Front River; dredging between Cross Tides and the city to increase the tidal prism above the city; widening the channel in front of the city to 600 feet and deepening to a depth of 21 feet at mean high water. To increase the volume of flow in the North Channel, it was proposed to obstruct the flow of South Channel, at the westerly end gradually with a view to its complete closure, if found desirable. In order to regulate the width of the river spur dikes were constructed throughout the length of North Channel. Figure No. 1 shows the location of all improvements constructed prior to 1890.

The first extensive survey of the harbor was made in 1890. It consisted of tidal observations at a number of points, velocity and volume measurements in the main channels and hydrographic surveys. The purpose of this survey was to determine the best alignment and cross sections for a channel from the sea to Savannah in which there would be a uniform tidal range, a mean velocity of 2 feet per second and a

navigable depth of 22 feet at mean high water.

Based on this study, a revised project for 26 feet at mean high water was authorized by Congress. The work accomplished under this authorization included the partial removal of Kings Island to relieve the obstruction to both the flood and ebb flows; partial removal of Marsh Island and closing of the channel to the north; constructing a training wall downstream from the lower point of Marsh Island for a distance of about one mile; a deflecting jetty into south channel; training walls generally connecting the ends of all previously constructed spur dikes and Cockspur Island Training Wall (South Jetty); dredging a channel south of Oyster Bed Training Wall (North Jetty). The Training walls were spaced to provide a surface width of about 600 feet at Savannah, the width increasing downstream to about 2000 feet at the inner end of the jetties and a constant width of 2500 feet between the jetties. The work under this improvement was reported completed in 1896 and the project dimension of 26 feet at mean high water obtained. After completion of this work further measurements of tidal planes and tidal volumes were made. The results are tabulated in Tables I and II.

In 1912 work was commenced on a project which provided for a channel 30 feet M.L.W. and 500 feet wide from deep water to Sta. 190; 26 feet M.L.W. and 400 feet wide to Sta. 107 and 21 feet M.L.W. and 300 feet wide to Sta. 103. These improvements were to be accomplished by dredging and raising all training walls, closure dams and jetties to mean high water. See plate No. 2 for station numbering.

In 1926 the harbor was extended to Sta. 90 by a channel with a depth of 21 feet M.L.W. and a width of 200 feet. At this time, the areas behind the training walls were generally filled to about half tide level which decreased the tidal prism considerably.

The next general improvement was commenced in 1936 and provided for a channel 30 feet M.L.W. and 500 feet wide from deep water to Sta. 190; 30 feet M.L.W. and 400 feet wide to Sta. 107, 26 feet M.L.W. and 300 feet wide to Sta. 103 and 21 feet M.L.W. and 200 feet wide to Sta. 89.

The present project completed in 1951 provides for a channel 36 feet M.L.W. and 500 feet wide from deep water to Sta. 194; 34 feet M.L.W. and 400 feet wide to Sta. 103 and 30 feet M.L.W. and 200 feet wide to Sta. 81. All improvements since 1895 have been constructed within the widths established by the training walls and jetties constructed at that time and which were designed to produce and maintain a channel depth of 26 feet at mean high water or about 19 feet at mean low water.

Tidal Data

The tides of the Savannah Harbor are of the semi-diurnal type with a tidal range of about 6.75 feet at the mouth and 7.5 feet at the city. Tidal data at the 6 base tide stations for selected years are given in Table I and the location of gages shown on Fig. 2. Where satisfactory records were available, those of the year following an improvement has been used so as to show the effect of the improvement on tidal events. Elevations are referred to Pulaski Datum, the mean low water at the mouth of the river for 1890.

TABLE I
TIDE DATA

Year	Elevation		Range Feet	Lunitidal Interval	
	MLW	MHW		LW	HW
			Pulaski (190)		
1889	0.00	6.97	6.97	1.48	7.26
1895	0.00	6.63	6.63	-	-
1921	0.07	7.02	6.95	1.55	7.42
1935	0.18	6.94	6.76	1.38	7.38
1940	-0.11	7.04	7.15	1.39	7.35
1945	0.18	7.14	6.96	1.31	7.37
1952	0.58	7.32	6.74	1.22	7.32
			Fort Jackson (135)		
1889	0.72	7.33	6.61	2.84	8.10
1895	0.88	6.89	6.01	2.77	8.10
1921	0.72	7.38	6.56	2.65	8.39
1935	0.17	7.37	7.20	2.04	7.69
1940	-0.16	7.56	7.72	2.09	7.87
1945	-0.03	7.53	7.59	1.98	7.78
1952	0.13	7.57	7.44	1.90	7.84
			Bull Street (118)		
1889	1.34	7.41	6.07	2.94	8.24
1895	1.25	6.95	5.70	2.90	8.14
1921	0.78	7.51	6.73	2.82	8.47
1935	0.09	7.50	7.41	2.26	7.88
1940	-0.21	7.72	7.94	2.23	7.97
1945	-0.06	7.72	7.78	2.12	7.88
1952	0.07	7.76	7.69	2.05	7.93
			Kings Island (98)		
1889	3.02	7.48	4.46	4.08	8.62
1895	2.95	7.15	4.20	3.91	8.40
1921	1.36	7.50	6.14	3.56	8.80
1935	0.46	7.49	7.03	2.66	8.31
1940	0.08	7.79	7.71	2.61	8.34
1945	0.22	7.80	7.58	2.57	8.35
1952	0.09	7.85	7.76	2.28	8.19
			Sugar Refinery (90)		
1935	0.70	7.61	6.91	-	-
1940	0.07	7.77	7.70	2.89	8.50
1945	0.36	7.92	7.56	2.74	8.44
1952	0.17	7.86	7.69	2.31	8.24
			Coastal Highway Bridge (78)		
1945	0.92	7.92	6.98	3.00	8.74
1952	0.30	7.93	7.63	2.54	8.39

The time of tidal events is shown in hours after the moons transit of the meridian through the Quarantine Gage. The tidal events follow the normal pattern to be expected. With one exception, with each improvement there has been a marked increase in the tidal amplitude as it travels upstream along with a speeding up in the arrival time of both high and low water. In the exceptional year 1921, there was a delay in the time of both high and low water over 1889 at Quarantine and a delay in the time of high water at all gages. This was no doubt due to the resistance to the free movement of the tidal currents caused by the construction of the entrance jetties and training works. Figure 3 shows graphically the high and low water planes and tidal ranges for 1895, 1921, 1935, 1946 and 1951.

With every improvement since 1921, there has been a marked increase in both the flood and ebb volumes.

TABLE 2

TIDAL VOLUMES 1889 to 1950
(millions of cubic feet)

Year	Flood Volumes		Ebb Volumes	
	Sta. 181	Sta. 193	Sta. 181	Sta. 193
1889	1448		1757	
1895	1227		1625	
1921		1280		1655
1930		1389		1845
1940		1904		2360
1950		2243		2706

The volume measurement of 1889 and 1895 were taken at Sta. 181 which at that time was considered to be the mouth of North Channel. The large reduction in volume in 1921 from that of 1889 was probably due to the construction of the training works which materially reduced the width of the river from the city to sea and thereby its volume.

Table 3 shows the effect of tidal range on current velocities and salinities. This series of measurements were made following the completion of the present project. It is to be noted that the maximum bottom flood velocities up to Sta. 130 for all other than neap tides, exceed 2 feet per second and during spring tides exceed 3 feet per second whereas the bottom ebb velocities are in all cases considerably less. The same condition in general, holds true for the average velocities. During neap tides at Station 193 through 153 bottom salinities were considerably higher than on spring and mean tides whereas top salinities were considerably less. Minimum salinities were higher on both bottom and top for neap tides at Stations 173, 163 and 153. These same conditions would probably hold true through Station 120 had the fresh water inflow been less. During the past year the Sugar Refinery has had difficulty in their refining process due to high salinities. A salinity of about 5.5 parts per thousand has been recorded at their plant located at Sta. 90. The invert of the intake line is at -5.0 feet M.L.W. The only time any salinity has been encountered has been on neap tide and low fresh water inflow.

TABLE 3
EFFECTS OF TIDAL RANGE ON CURRENT VELOCITIES & SALINITIES

Station No.	Date	Clyo Discharge (c f s)	Tidal Range (feet)		Maximum Velocities *				Average Velocities *				Salinity *			
					Flood		Ebb		Flood		Ebb		Maximum		Minimum	
			Flood	Ebb	Top	Bot.	Top	Bot.	Top	Bot.	Top	Bot.	Top	Bot.	Top	Bot.
193	10-12-50	5670	8.7	8.8	3.5	4.0	5.6	3.1	2.3	2.3	3.8	1.7	26.5	28.2	14.2	18.0
193	5-26-50	7020	6.7	6.4	3.4	2.1	4.9	1.7	2.1	1.0	3.3	0.9	26.0	29.8	14.2	25.2
193	8- 7-50	6700	3.7	4.5	2.0	2.7	5.3	2.2	0.5	0.9	2.3	0.8	17.1	31.0	12.2	28.3
183	10-12-50	5670	8.9	8.0	3.8	3.2	7.4	3.0	2.3	2.3	4.6	2.1	25.1	27.4	11.2	16.3
183	8- 7-50	6700	3.9	4.8	1.1	2.2	3.9	1.2	0.8	1.1	2.2	0.8	19.0	30.1	10.9	28.3
173	10-12-50	5670	9.0	9.1	3.8	3.7	6.5	1.8	2.2	2.1	4.1	1.5	24.7	26.7	8.2	13.6
173	8-18-50	4530	7.0	7.4	2.6	2.8	5.0	1.3	1.8	1.5	3.6	0.8	20.9	27.3	8.9	19.1
173	8- 7-50	6700	4.0	4.8	0.7	1.9	4.2	0.6	0.5	1.3	2.6	0.4	14.6	30.0	9.7	27.9
163	10-12-50	5670	9.1	9.2	2.7	2.7	5.6	1.9	2.0	1.9	3.4	1.3	21.3	25.3	5.8	8.4
163	8- 7-50	6700	4.0	4.9	1.1	1.4	4.0	0.4	0.7	1.0	2.5	0.3	14.4	28.5	8.2	24.6
153	10-12-50	5670	9.3	9.1	5.4	3.1	5.7	1.5	2.9	1.4	4.2	1.1	17.4	24.1	3.6	4.8
153	8- 7-50	6700	4.2	5.0	1.4	1.8	3.8	0.8	0.9	1.3	2.3	0.5	10.5	28.1	6.6	22.7
143	9-14-50	11,500	9.2	9.1	3.9	3.3	5.6	2.7	1.6	0.8	3.0	1.6	5.0	18.4	0.1	0.1
143	7-20-50	9120	6.4	6.9	2.6	2.6	4.4	1.9	1.6	1.5	2.7	1.3	9.2	16.9	0.6	0.9
143	8- 5-50	6700	4.3	5.2	1.4	1.9	3.9	1.4	1.1	1.1	2.5	1.0	9.3	26.0	5.9	12.3
130	9-14-50	11,500	9.4	9.3	2.8	2.6	5.2	3.2	1.9	1.8	3.6	2.2	1.3	12.1	0.0	0.0
130	9-28-50	7600	6.7	6.9	2.9	1.9	4.5	1.3	2.4	1.0	3.3	1.0	6.4	15.7	0.2	0.6
130	9-19-50	13,500	6.4	6.7	1.5	2.6	4.2	2.0	1.1	1.7	2.8	1.1	1.0	15.4	0.0	0.0
120	9-14-50	11,500	8.4	8.7	2.8	1.9	4.2	3.4	1.8	1.3	2.8	2.1	0.3	1.1	0.0	0.0
120	9-19-50	13,500	6.5	6.8	1.7	1.1	3.4	2.5	1.0	1.1	2.5	1.2	0.2	10.9	0.0	0.0
109	8-29-50	6200	10.0	10.2	3.1	2.1	4.4	2.1					1.9	7.8	0.0	0.0
109	9-19-50	13,500	6.6	6.8	1.4	0.9	3.5	2.3	1.0	1.1	2.5	1.2	0.0	0.0	0.0	0.0
109	9-14-50	11,500	9.5	9.3	2.1	1.3	4.4	3.0	1.8	1.3	2.8	2.1	0.0	0.0	0.0	0.0

* Velocities in feet per second - Salinity in parts per thousand

Channel Changes

Table 4 gives the natural changes in cubic yards for the several reaches in the harbor. It should be noted that from 1923 to 1935, the greatest shoaling occurred below Sta. 134. However, from 1943 to 1953, the reverse is true. It is not practical to prepare natural channel changes for the bar channel. The material dredged from the bar channels from 1927 through 1931 averaged about 3,300,000 cubic yards annually whereas from 1946 through 1950 the average has been only about 800,000 cubic yards. Although these quantities do not furnish as true a picture as natural changes they definitely indicate a sharp reduction in shoaling rates.

Sediment Sources

From Table 4, it can be readily seen that shoaling is a serious problem and at present is the major challenge facing those responsible for development and maintenance of our deep water harbors. In any studies to determine remedial measures to be taken to reduce the rate of shoaling it is most desirous that the source of the shoaling material be known. There are possibly three major probable sources (a) sediments brought downstream by fresh water inflow, (b) sediments from large expanses of adjacent marshes and (c) material from off-shore brought in by the flood tides.

Samples of off-shore material above, opposite and below the harbor entrance, along with samples from the shoals in the harbor, the adjacent marsh lands and the sediment entering the harbor by the Savannah River were collected and analyzed in an effort to determine the source of the material forming the shoals. It was thought that possibly some rare mineral might be found in the shoal areas that would be common to only one probable source. The results of these tests furnished no information of value as the same minerals were found in each of the samples.

The sediments brought down by the fresh water inflow were long considered to be the primary source of shoaling and until recently little thought has been given to other possible sources. A sediment sampling program was established in the fall of 1949 on the Savannah River to determine the quantity of sediment in transit. One station was established about 50 miles above Savannah at the head of the tidal prism. Another station was established about 1/2 mile below the Clark Hill Dam then under construction. Samples were collected daily at these stations for the first year and subsequently 3 times a week. Samples were taken with a D-43 depth integrating type sampler and filtered through a standard crucible with an asbestos mat. No attempt has been made to determine the bed load as the quantity is believed small and it is deposited in the upper limits of the harbor where it can be easily removed by pipeline dredges. For the past 5 years the natural change in this area of the harbor amounted to an average of only 90,000 cubic yards annually.

Figure 4 shows the results of the sampling program at Clyo. Filling of the Clark Hill reservoir was commenced 21 December 1951.

TABLE 4

SAVANNAH HARBOR - NATURAL CHANGES IN CU. YDS. - (SHOALING-) (SCOUR +)

Year	82-100	100-107	107-120	120-134	134-142	142-166	166-194	194-205	TOTAL
1923		+153,995	+120,764	+291,068	+462,656	-258,326	-1,037,485	-9,052	-276,380
1924		-424,642	-477,403	-464,930	-400,470	-1,654,478	-1,751,290	-988,482	-6,161,695
1925		+271,445	+76,348	+146,239	+510,613	-502,770	-1,785,206	-773,927	-2,057,258
1926		-138,472	+7,530	-691,411	-440,225	-285,754	-112,715	-589,636	-2,250,683
1927		-59,600	-315,557	-947,489	+92,800	-1,254,255	-1,369,042	-190,080	-4,043,223
1928		-146,637	+65,271	-529,698	-250,265	-189,584	-159,236	+178,814	-1,031,335
1929	-114,461	-104,670	-161,293	-41,175	-60,985	-898,707	-2,152,659	-2,201,695	-5,735,645
1930	-171,334	+20,440	-145,905	+38,730	+349,520	-736,770	-1,552,105	-1,154,360	-3,351,734
1931	-285,337	+329,580	-56,604	-656,703	-484,914	-1,337,700	-521,262	+59,272	-2,953,668
1932	-	-468,422	+13,482	-1,077,708	+38,743	-1,649,983	-1,958,525	-592,935	-3,053,668
1933	-137,340	-64,495	+251,900	-525,567	-101,894	-21,746	+296,171	-253,650	-556,621
1934	+26,777	+80,525	-384,098	-3,573,903	-364,065	-2,502,710	-2,946,839	-243,179	-9,907,492
1935	-2,849	-46,242	-355,170	-1,201,694	-591,035	-1,994,737	-617,745	-205,412	-5,014,884
1938	-240,149	+63,666	+19,503	-2,296,368	-567,418	-1,278,918	-837,836	+815,129	-4,321,391
1939	+154,603	-109,333	-251,982	-1,582,910	-528,710	-255,118	-236,452	-677,695	-3,497,597
1940	-198,133	-78,450	-381,693	-1,498,811	-1,017,856	-1,397,668	+23,447	-29,816	-4,578,980
1941	-231,240	-30,528	-842,484	-1,408,368	-1,020,496	-934,908	-1,010,040	-304,968	-5,783,032
1942	+157,716	+69,012	+177,088	-1,629,888	-800,376	-534,216	-754,232	-582,276	-3,897,182
1943	+5,853	-149,580	-596,280	-1,613,820	-131,508	-1,722,816	+17,172	-271,248	-4,462,227
1944	-25,608	-38,820	+25,548	-2,024,664	-907,716	-2,683,548	-2,721,084	-804,404	-9,180,296
1945	-140,556	-319,116	-508,680	-3,173,256	-1,003,308	-2,019,912	-1,399,776	-80,134	-8,644,738
1946	+11,700	+52,776	-91,392	-2,154,532	-641,112	-3,409,512	-2,795,604	-1,962,804	-10,990,480
1947	-132,156	-113,556	-372,816	-3,232,668	-1,468,176	-2,364,612	-480,720	-69,708	-8,234,412
1948	-247,539	+304,724	+508,666	-1,402,684	-1,304,877	-1,897,760	-1,375,481	-794,890	-6,209,841
1949	-543,077	-440,740	-80,106	-2,585,414	-694,046	-3,380,007	-5,798,887	-140,543	-13,381,737
1950	-233,185	-126,258	-1,060,776	-3,372,588	-1,282,640	-3,208,206	+693,050	+3,753	-8,586,850
1951	-486,779	-268,703	-725,217	-3,604,663	-882,519	-1,308,238	-1,357,654	-122,915	-8,756,688
1952	-815,779	-156,205	-337,156	-3,079,143	-334,713	-168,016	+1,174,998	-98,963	-2,045,493
1953	-191,223	-542,238	-1,392,466	-3,443,426	-606,448	+211,722	-580,712	-431,984	-6,976,775

the two years prior to this date, the average sediment concentration below Clark Hill Dam and at Clyo was 0.0570 and 0.0440 grams per liter respectively. The drainage area below Clark Hill Dam lies mostly in the Coastal Plane which contributes very little sediment and accounts for the lower concentration at Clyo. The total sediment load passing Clyo during this two year period amounted to about 764,000 tons. Samples taken from the shoal areas in the vicinity of Sta. 130 in the harbor and tested in the laboratory indicates a dry weight of from 320 to 540 pounds per cubic yard. Using the lower value, the total quantity of the shoaling in the harbor that could be attributed to sediment from upstream during 1950 and 1951 was about 5 million cubic yards. During this same period the natural change in the harbor exclusive of the bar channel was about 17 million cubic yards. From December 1951 to October 1953 the sediment concentration below Clark Hill Dam and at Clyo has been 0.0273 and 0.0360 respectively. This is a marked reduction in concentration from the preceding two years and probably reflects the effects of the Clark Hill Reservoir. The increase in concentration at Clyo over Clark Hill is probably due to the continued aggressive erosion of the river banks. The total load passing Clyo from December 1951 to October 1953 amounted to about 689,000 tons or about 4.3 million cubic yards of shoaling material. During this same period the natural change in the harbor amounted to about 9 million cubic yards. The results of this sampling program indicates that probably not over 50 percent of the shoaling in the Savannah Harbor can be attributed to sediment brought in by the Savannah River. From the meager information available, it appears probable that the construction of the Clark Hill Project may reduce the sediment load of the river by from 15 to 20 percent.

The next most logical major source of shoaling material is probably that brought in from off-shore by the tidal currents. It has been established that there is a large quantity of fine material moving generally in a southerly direction immediately off-shore as littoral drift. This material when crossing the bar channel during flood tide encounters currents that are adequate to maintain it in suspension. When the current slackens, the material is deposited and as the bottom ebb currents are less than those of the flood and of shorter duration, the material either remains in place or is moved only part way back to sea. On the strength of the next flood, currents may be adequate to again place these sediments in suspension. This movement of sediments to and fro continues with a progressive movement upstream until such time as bottom velocities are inadequate to move the material. This process of movement is borne out by the material comprising the shoals. In general, the shoal areas at the lower end of the harbor contain a considerably higher percentage of sand than shoals near the city. The shoals at the upper limit of the salt water wedge about Sta. 130 contain practically no sand particles.

Any quantative determination of off-shore material moving into the harbor would be quite involved and costly and the results would be questionable due to the many variables such as tidal range, winds, fresh water inflow, etc. A representative measurement would have to extend through a lunar tidal cycle. One rather elaborate measurement

was made during a mean tide at Sta. 190 in an attempt to obtain some quantative data on material passing this station during the flood and ebb periods. The river was divided into 5 sections of about equal area. Samples and velocities were obtained at the midpoint of each section every hour at 3 foot intervals of depth for an entire tidal cycle. A P-46 point intergrating type sampler was used. Some difficulty was encountered in its operation in high salinities due to leakage of current and shortages. Also the rate of filling of this type sampler depends on the velocity. Where velocities were low adequate time was not available to obtain point samples and one depth intergrated sample was obtained. It was later found that by raising the discharge port, point samples could be obtained even in slack water. It is acknowledged that relocating the port defeats to some extent the purpose of the design of this sampler. Figure 5 shows the velocities, salinities and sediment concentrations for 1 vertical. This vertical is just south of the channel limits but is used as the data collected is more complete than on other verticals. The heaviest concentration was found near the bottom during the strength of the flood. The results of this one measurement showed 4618 tons passing on the flood and 2970 tons on the ebb. A difference of 1640 tons more on the flood than ebb. This would indicate that probably material brought from off-shore on the flood is of a more significant quantity than previously thought. This is more the case now than in past years. During the period from 1927 through 1931, there was an average of about 3,300,000 cubic yards dredged from the bar whereas during the period from 1946 through 1950, only about 800,000 cubic yards have been dredged. In 1926 the project depth on the bar was 30 feet and the flood tidal volume about 1280 million cubic feet whereas in 1950 the project depth on the bar had been increased to 36 feet, a 20 percent increase and the flood tidal volume increased to about 2243 million cubic feet, an increase of about 75 percent. This large increase in volume with the comparatively small increase in cross section has so increased flood velocities that littoral drift that was previously deposited in the bar channel now is carried to the inner harbor and deposited.

The third possible source of shoaling material is the vast expanse of marsh lands adjacent to the harbor. There is no way to evaluate just how much material is contributed by this source. No doubt, during spring tides, some material is brought into the channel by the falling tide. Due to the extremely fine material comprising the shoals in the vicinity of the city it has been found necessary to construct ring dikes with waste wiers around all spoil areas forming sedimentation basins to prevent immediate run-back of spoil and future erosion.

Dredging

There has been considerable discussion in the past as to the proper type of equipment to be used for the removal of shoals. As a general rule, standard cutter-head dredges are used in protected harbors and the spoil pumped to adjacent spoil areas. Where spoil areas are available, this is the least complicated and most inexpensive method. The bar channels are maintained by hopper dredges and the spoil dumped at

sea. Agitation dredging has been quite often used with apparent success. Normally a hopper dredge is used for this purpose during the period of the ebb tide when velocities are sufficiently high to maintain the material in suspension and transport it to sea. Considerable thought and study should be given to the location to be dredged and ebb velocities before adopting the agitation method. The average ebb velocities in Savannah Harbor below the City are about 2 feet per second for about 6 hours or 21,600 seconds. For only about 4 hours or 14,400 seconds do velocities exceed 2 feet per second which is the velocity considered required to assure that the material is kept in suspension. On this basis, material agitated 1 hour after high tide as much as 28,800 feet distant from deep water off-shore might be carried to sea and deposited in deep water where it would not be returned on the next flood tide. This distance would be continually reduced as the tide dropped. On these assumptions, little or no lasting benefits are accomplished by agitation dredging in the inner Savannah Harbor. It is true that agitation regardless of location normally provides deeper water in the immediate channel but this condition is probably only temporary as the material is probably deposited in thin layers downstream in the channel and adjacent thereto and will be again moved into the area dredged by successive flood tides.

Remedial Measures

In order to prevent the movement of the littoral drift into the harbor during flood tide, the velocity of the flood currents must be reduced. This can only be accomplished by increasing the cross section area of the entrance channel or reducing the tidal prism. Although reduced velocities would prevent the movement of the littoral drift to the inner harbor, it would on the other hand probably increase the maintenance dredging in the bar channel by an equal amount.

The mountain and the piedmont area are the major source of the sediment load brought down by the Savannah River. This load will probably be decreased to some extent by the amount of sediment trapped by the Clark Hill reservoir and by better soil conservation practices in the future. However, due to the meandering nature of the Savannah River and the accompanying bank erosion, it is probable that sediments brought into the harbor from this source will always be appreciable.

It is possible to divert the fresh water flow around the Savannah Harbor. This would eliminate the fresh water flow through the Savannah Harbor, except for the portion that might enter through the Intracoastal Waterway. This should eliminate the major amount of the sediments of the Savannah River as a source of shoaling. This diversion would also materially reduce the tidal prism. The elimination of the fresh water would also eliminate the density currents in the harbor so that velocities throughout the vertical would be more nearly constant. This would reduce bottom velocities on the flood and increase these velocities on the ebb. Also by reducing the tidal prism, the velocities in the entrance channels would be reduced proportionately. This would all tend to reduce shoaling in the inner harbor to the minimum, but at the same time

greatly increase shoaling in the bar channels as velocities on both the flood and ebb would not be sufficient to move the littoral drift deposited in the bar channels. However, anything that can be done to move the location of shoaling in the harbor towards the mouth is desirable due to the critical lack of adequate disposal areas near the City for pipeline dredging.

This diversion could probably be economically justified if only the costs of dredging are considered. However, there are other problems that could far outweigh the savings in dredging. By diverting the fresh water, the harbor would become a sea water harbor throughout. Marine borers would then probably become quite a problem as practically all facilities in the harbor are constructed of timber. The replacement of these facilities with concrete would be an extremely costly undertaking. It may be that by flushing the harbor occasionally with fresh water that the marine life could be kept under control. Further and far more serious is the probable pollution of the harbor. The development of the City of Savannah is largely due to a diversified industry dependent on the availability of large quantities fresh water. Industries along the river include two large paper pulp plants, electric power, gypsum products, asphalt and sugar refinery. A large chemical plant is now under construction. All take large quantities of water from the Savannah River for processing purposes as well as use the river for disposal of waste products.

At the present time, during the summer months, there is for all practicable purposes a complete oxygen block in the vicinity of Station 130. The block is so complete that it destroys marine life. Bottom samples in this area show a 5 day BOD of 280 ppm with a loss on ignition of about 15 percent whereas immediately above the harbor there is practically no BOD, and loss on ignition is less than 0.5 percent. This high BOD is probably due to the trapping of organic material, both industrial and City waste, by the silt in the process of flocculation. The fresh water flow tends to flush some of these waste products through the harbor and its diversion could be disastrous and would certainly become a health problem unless all wastes were completely treated. As the industries were located along the harbor due to the abundance of fresh water for processing and disposal of waste it is not readily known whether they could survive if required to purchase water for processing and completely treat all waste.

SUMMARY

This paper, although based on data obtained in the Savannah Harbor will no doubt, in general, hold true in a large extent to similar harbors. However, it must be borne in mind that the tidal regimen depends on a number of factors that vary for every harbor. The more important of these factors are listed below though not necessarily in order of their importance.

1. Tides at entrance
2. Fresh water inflow

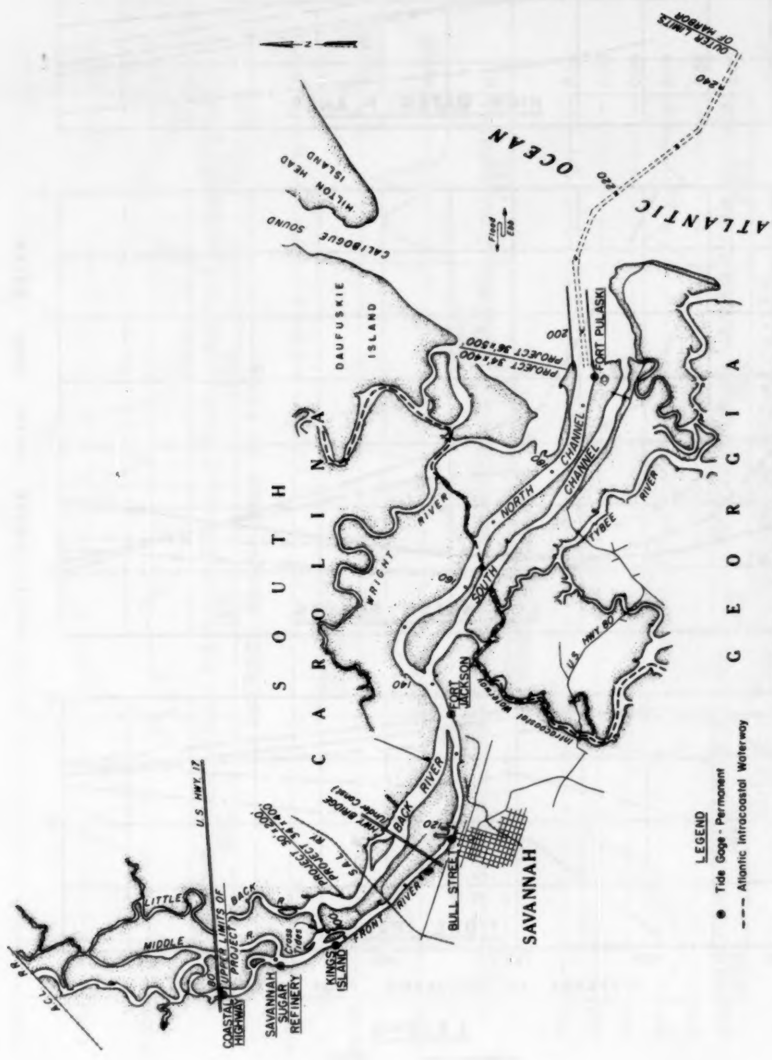
3. Salt water intrusion
4. Littoral drift
5. Shape of the waterway
6. Width
7. Depth
8. Character of bed material.

A change in any one of these factors could materially alter the entire regimen of the estuary under study. Any alteration of a harbor as drastic as the diversion of the fresh water inflow should be given a careful and thorough study. In order to evaluate the results to be expected from such a modification, and to obtain data on the velocity and salinity patterns, the construction and operation of a scaled model would be most desirable if not essential.

CONDITION OF SAVANNAH HARBOR
1890

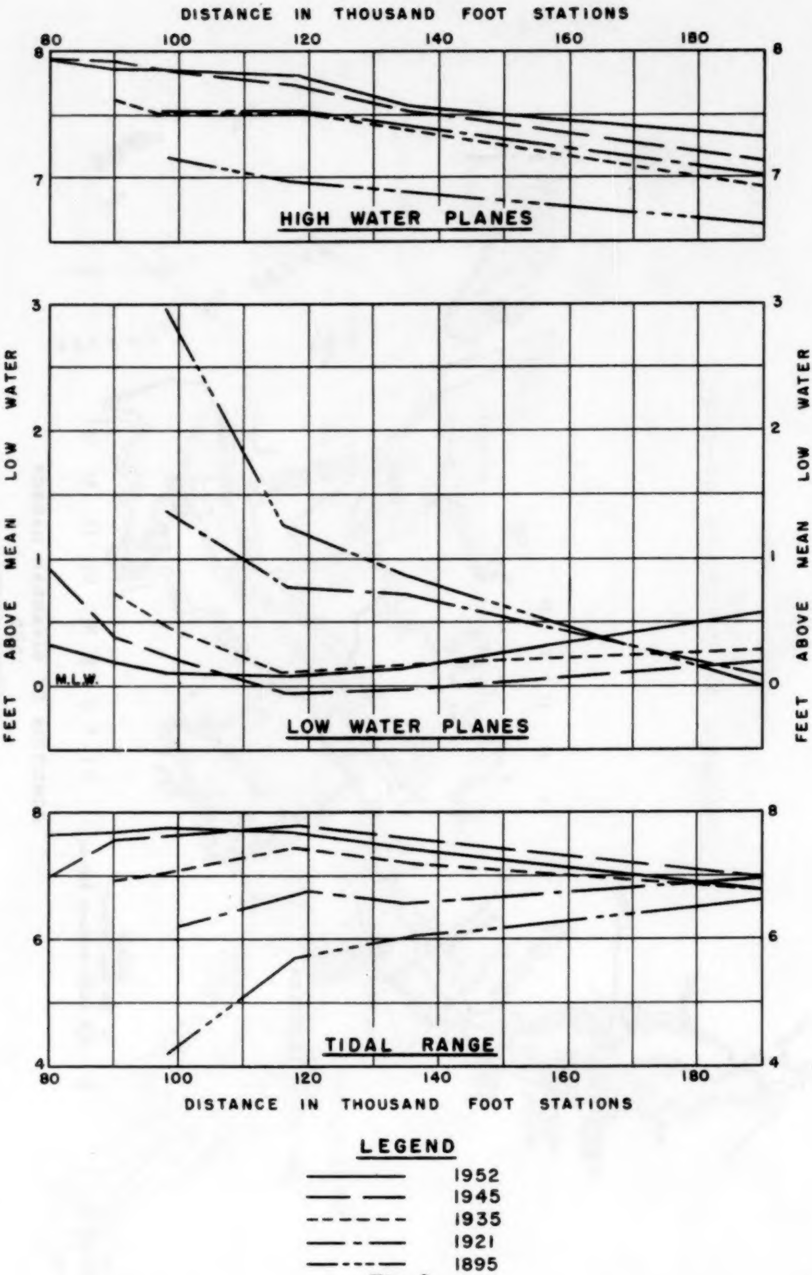
SCALE IN MILES

Fig. 1



CONDITION OF SAVANNAH HARBOR
1953

Fig. 2


DISTANCE IN THOUSAND FOOT STATIONS
80
100
120
140
160
180
8
7
HIGH WATER PLANES
3
2
1
0
M.L.W.
FEET ABOVE MEAN LOW WATER
LOW WATER PLANES
8
6
4
TIDAL RANGE
80
100
120
140
160
180
DISTANCE IN THOUSAND FOOT STATIONS
LEGEND
1952
1945
1935
1921
1895
Fig. 3

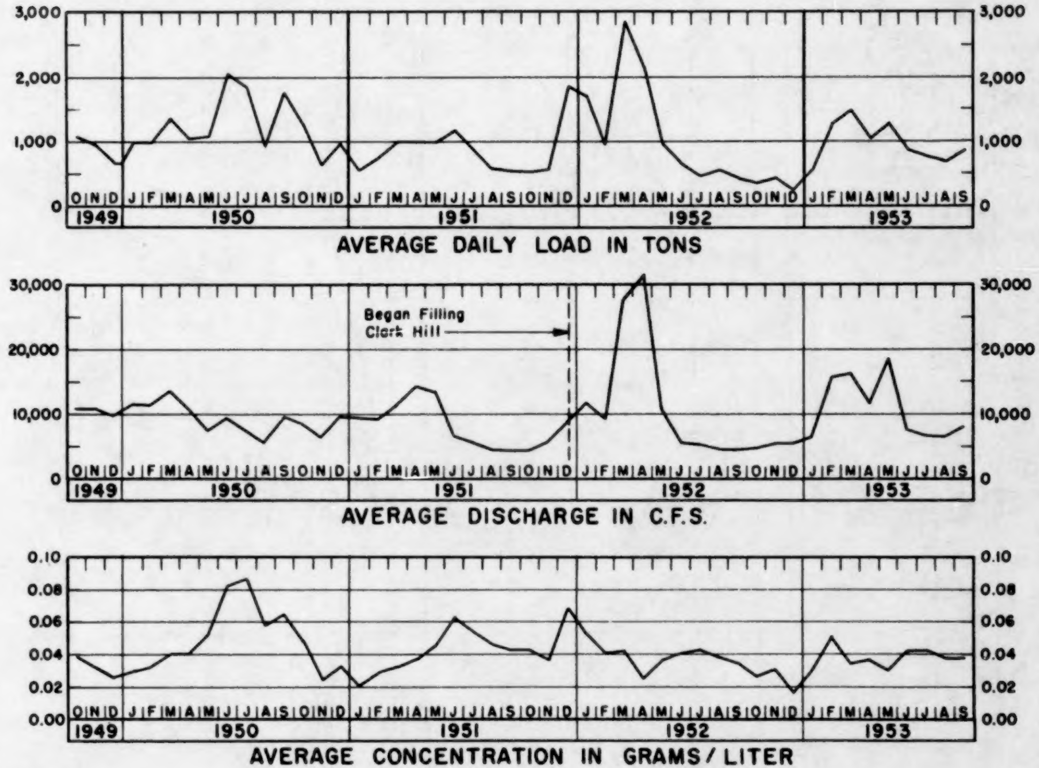
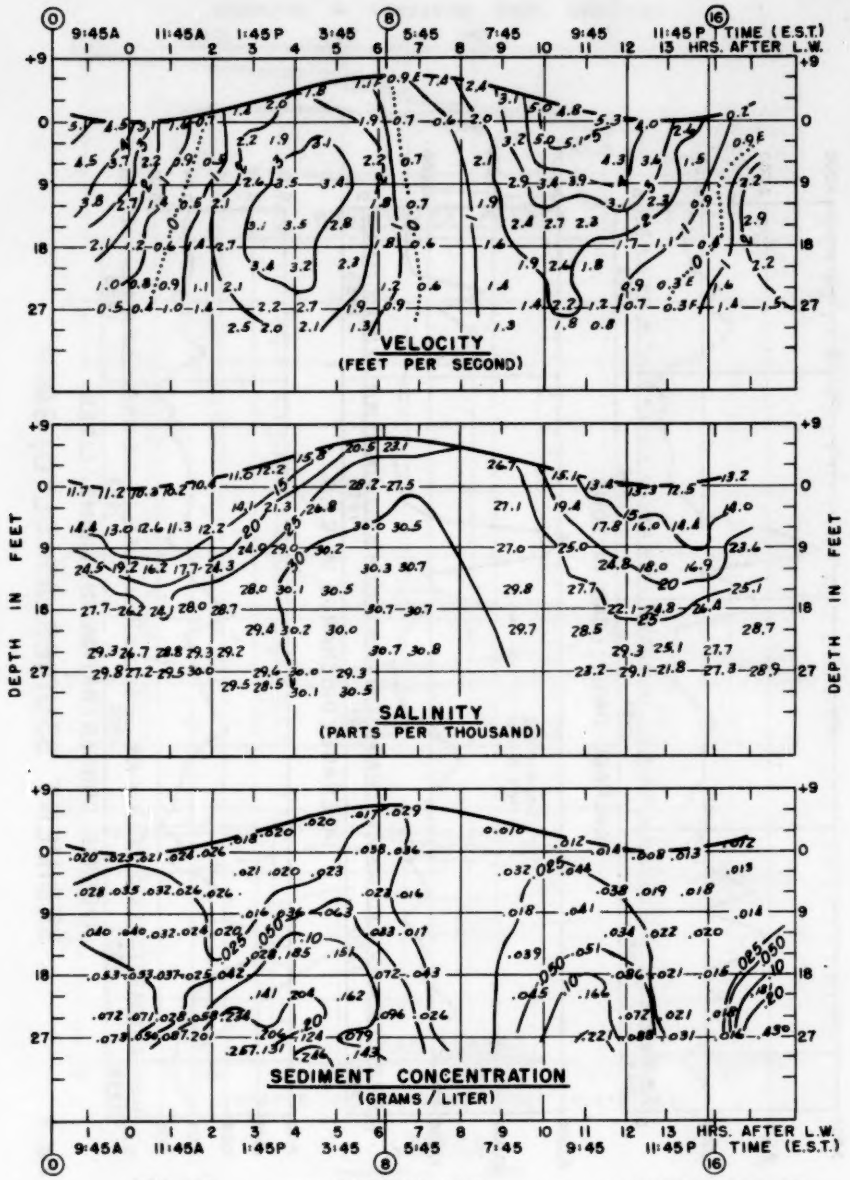


Fig. 4 SEDIMENT STUDIES AT CLYO, GA.



TIDAL RANGE: LOW -0.2 HIGH 6.55 LOW +0.2

WIND: DIRECTION - SSW AVG. M.P.H. 11.8

CLYO DISCHARGE 10 MAY 8,890

MOONS TRANSIT AT QUARANTINE MERIDIAN 8:52.3 A.M.

SAVANNAH HARBOR
STATION 193 - VERTICAL NO.4
MEAN TIDE - 12 MAY 1950

Fig. 5